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H1E EA

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US 4825894 A

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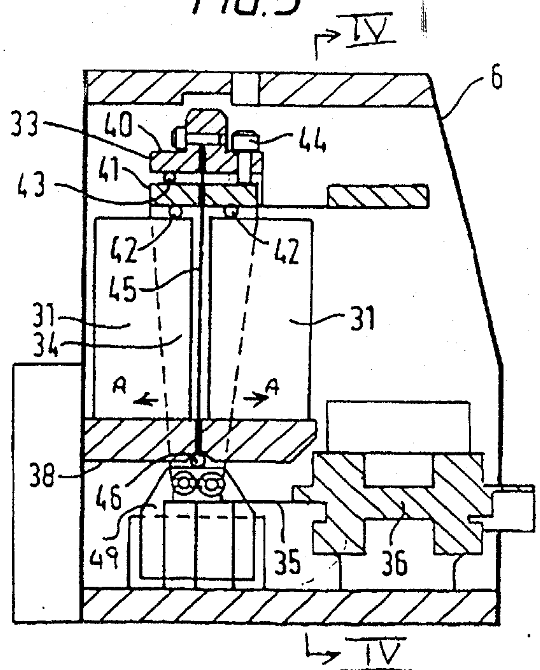
Online: WPI

(54) Electromechanical actuator

(57) An actuator comprising a pair of similar piezoelectric devices (31) each responsive to electrical signals to generate reciprocatory displacements, and link means (34) coupled to the devices to translate the respective displacements of the devices into a single set of reciprocatory displacements, the coupling between the link means and the devices being such that for each displacement generated by the link means the devices generate displacements in opposite directions. Also disclosed is a lathe employing the above actuator arrangement to accurately move a cutting tool in a reciprocatory manner. Applications include manufacture of contact lenses.

FIG. 3



GB 2 314 452

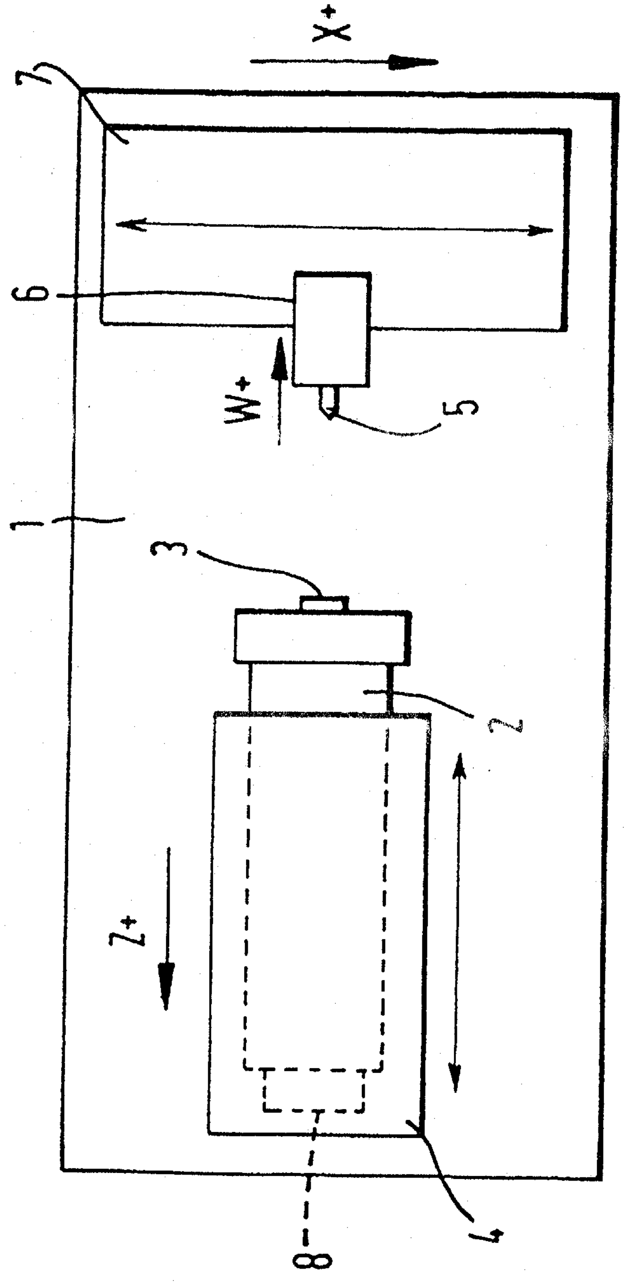


FIG. 1

FIG. 2

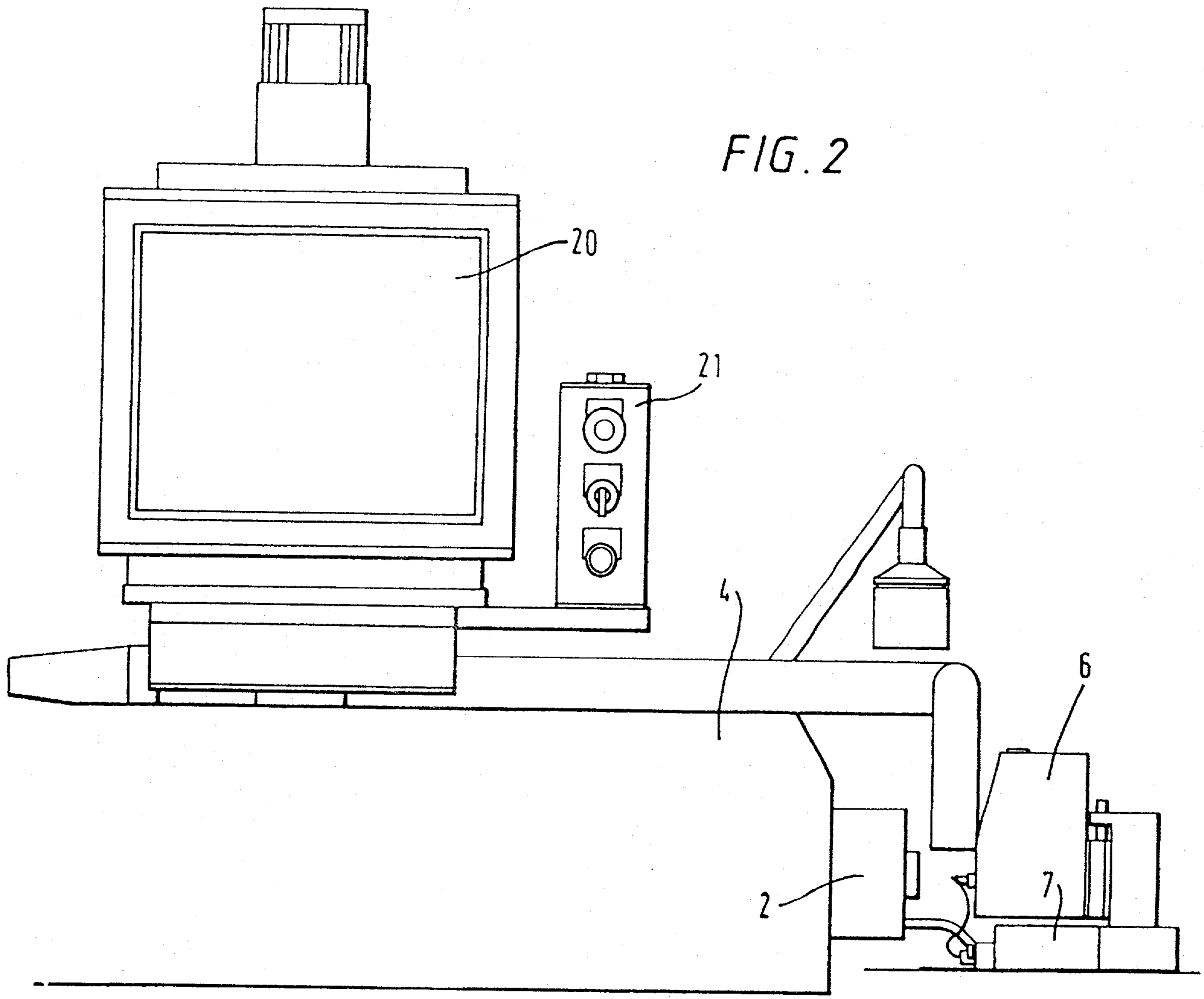


FIG. 3

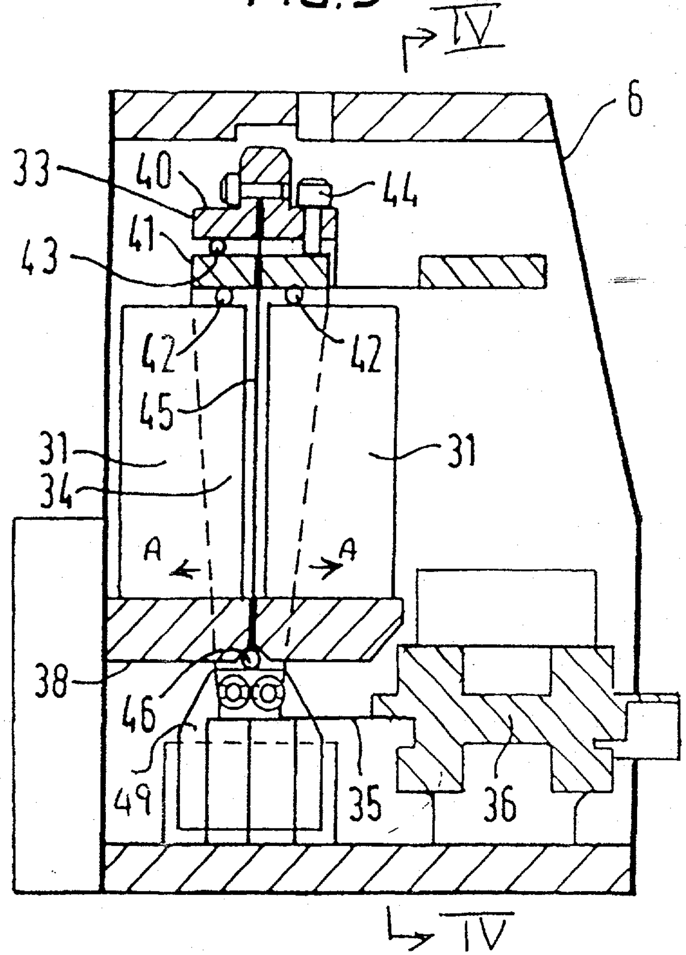

IV
IV
6
33
40
44
43
41
42
42
45
31
31
34
A
A
38
46
49
35
36

FIG. 4

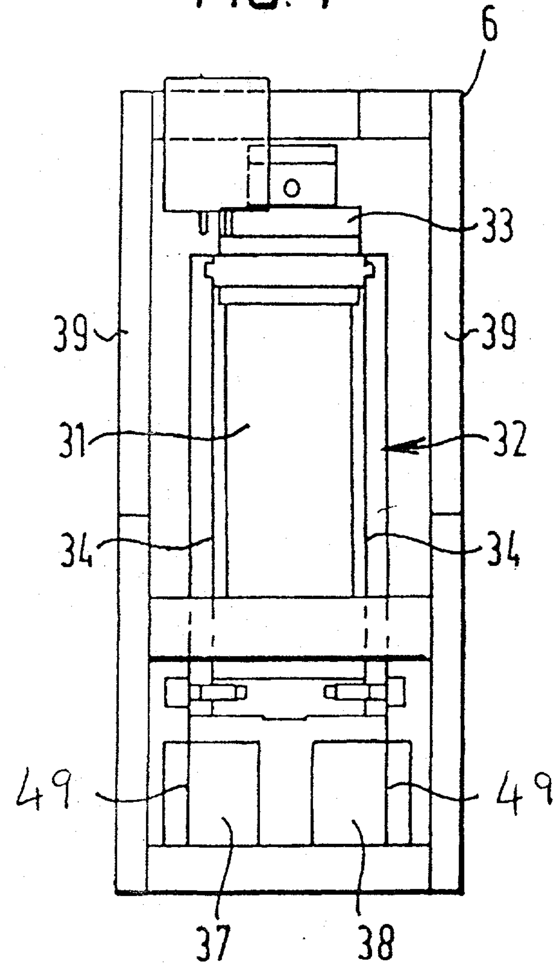

6
33
39
39
31
32
34
34
49
49
37
38

FIG. 5A

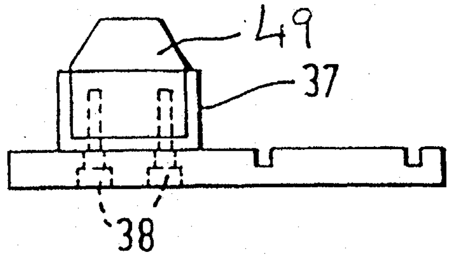


FIG. 5B

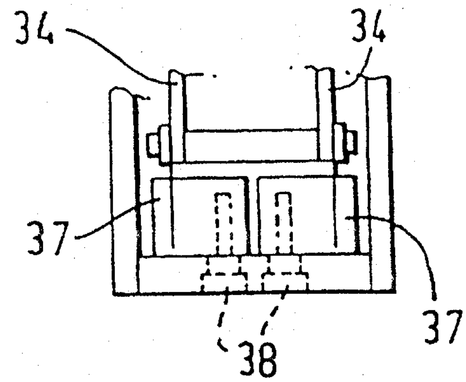


FIG. 6

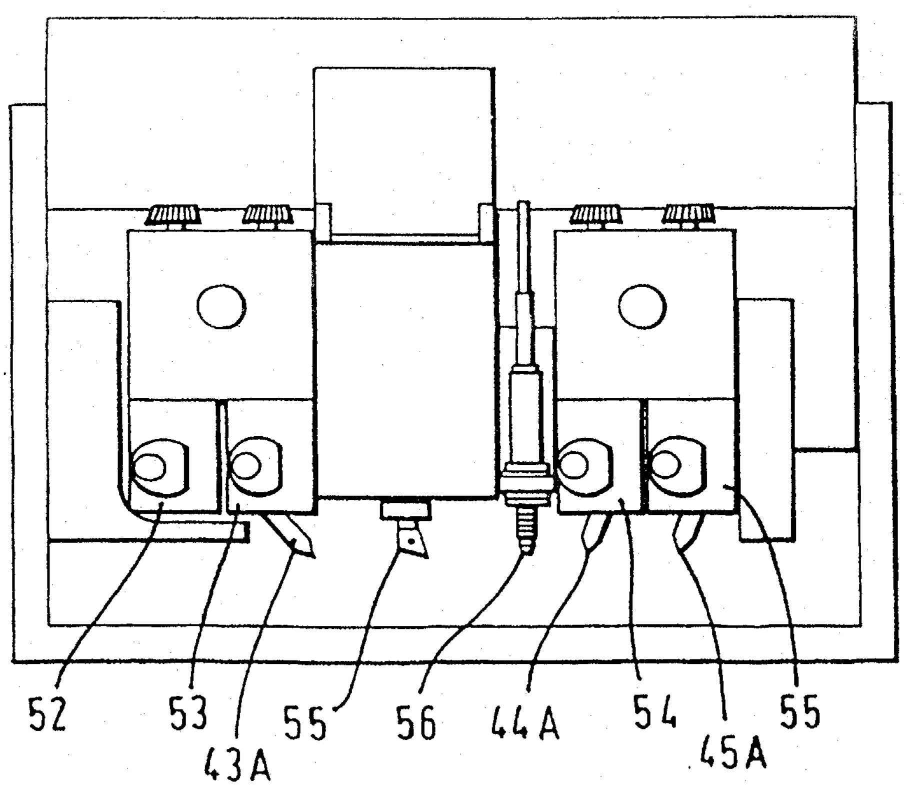


FIG. 7

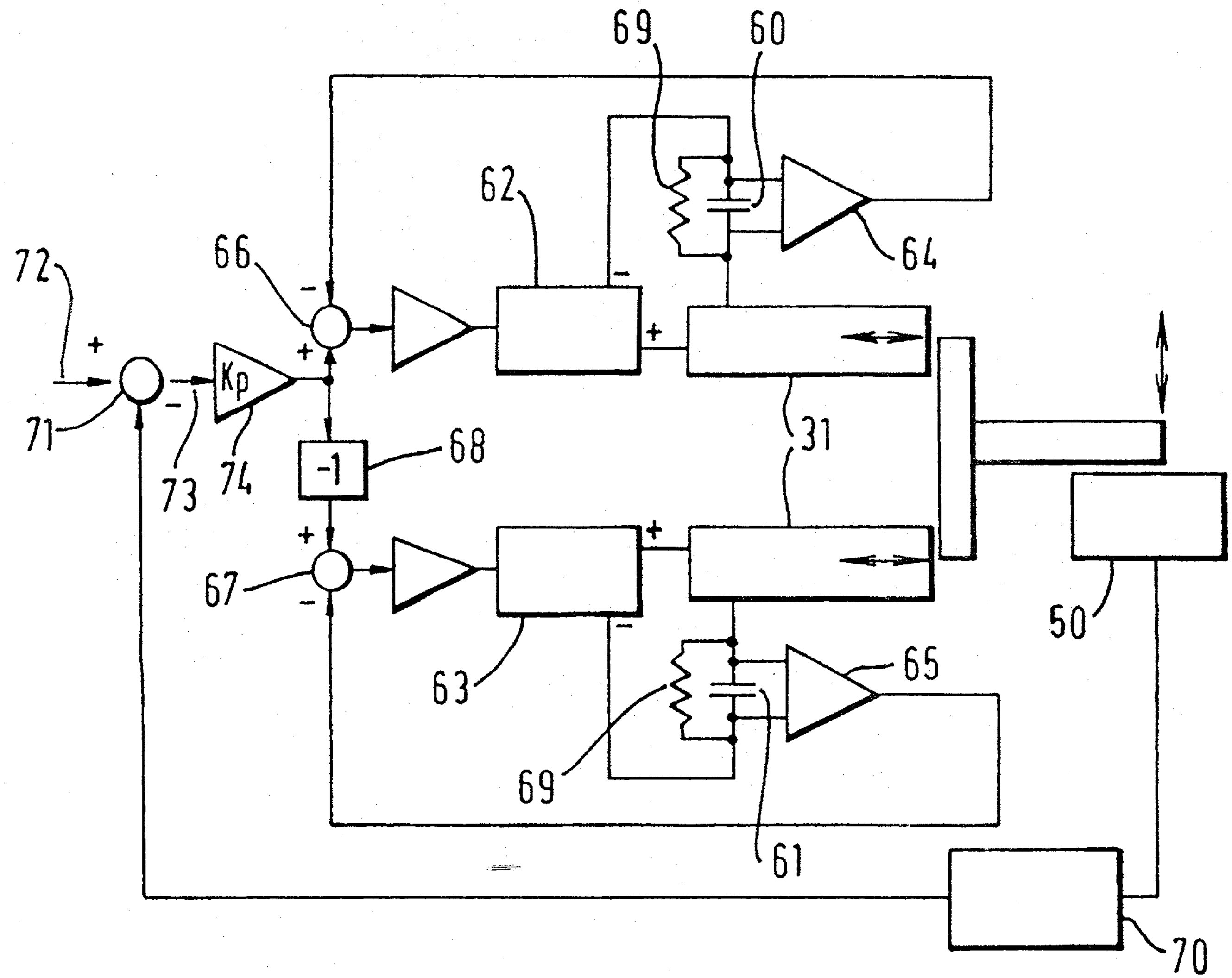
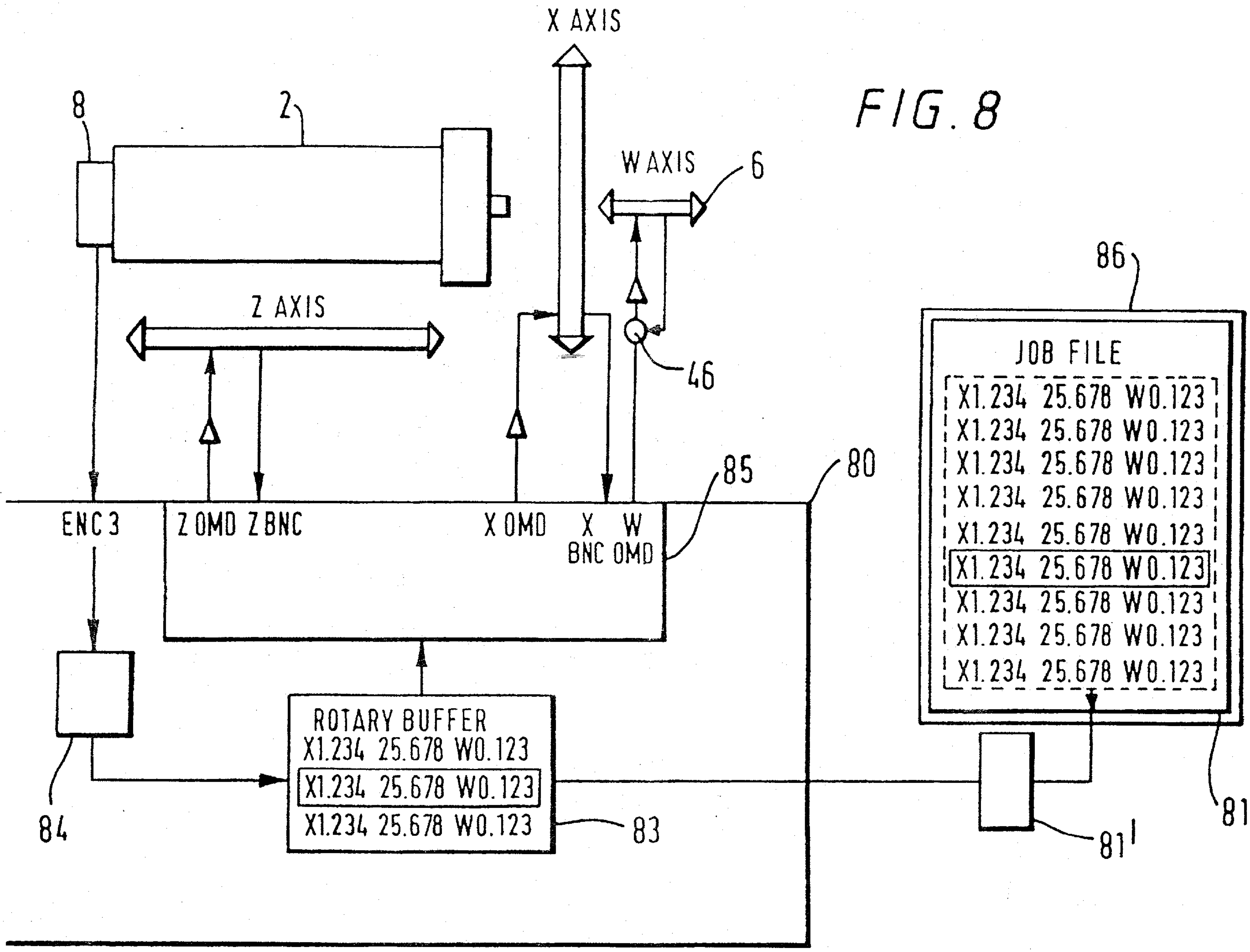
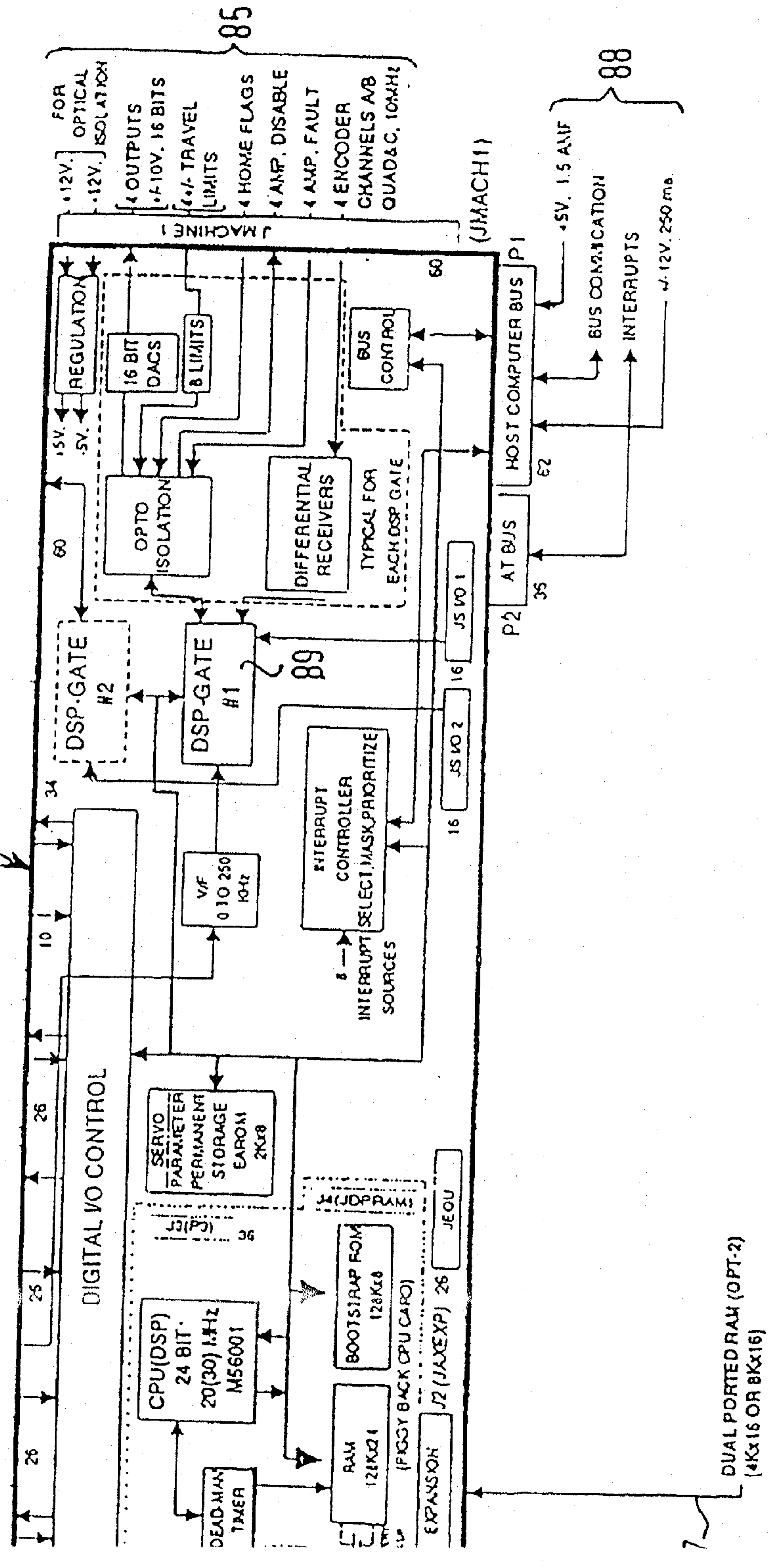


FIG. 8


X AXIS
8
2
W AXIS
6
Z AXIS
46
86
JOB FILE
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
85
80
ENC3
Z OMD
Z BNC
X OMD
X BNC
W OMD
ROTARY BUFFER
X1.234 25.678 W0.123
X1.234 25.678 W0.123
X1.234 25.678 W0.123
84
83
81'
81



85
FOR OPTICAL ISOLATION
+12V.
-12V.
4 OUTPUTS
+/-10V. 16 BITS
4+/- TRAVEL LIMITS
4 HOME FLAGS
4 AMP. DISABLE
4 AMP. FAULT
4 ENCODER CHANNELS A/B QUAD&C, 10MHz
J MACHINE 1
(JMACH1)
88
+5V. 1.5 AMP
BUS COMMUNICATION
INTERRUPTS
+/-12V. 250 ma.
P1
HOST COMPUTER BUS
E2
AT BUS
P2
35
60
REGULATION
+5V.
-5V.
16 BIT DACS
8 LIMITS
BUS CONTROL
OPTO ISOLATION
DIFFERENTIAL RECEIVERS
TYPICAL FOR EACH DSP GATE
JS I/O 1
JS I/O 2
16
DSP-GATE #2
DSP-GATE #1
89
80
34
10
V/F 0 TO 250 KHz
INTERRUPT CONTROLLER SELECT, MASK, PRIORITIZE
8 INTERRUPT SOURCES
26
DIGITAL I/O CONTROL
SERVO PARAMETER PERMANENT STORAGE EAROM 2Kx8
J4(JDPRAM)
J3(PJ)
36
JEOU
BOOTSTRAP ROM 128Kx8
25
CPU(DSP) 24 BIT 20(30) MHz M56001
(PIGGY BACK CPU CARD)
J2 (JAXEXP)
RAM 128Kx24
DEAD MAN TIMER
EXPANSION
DUAL PORTED RAM (OPT-2) (4Kx16 OR 8Kx16)

FIG. 9

FIG. 10

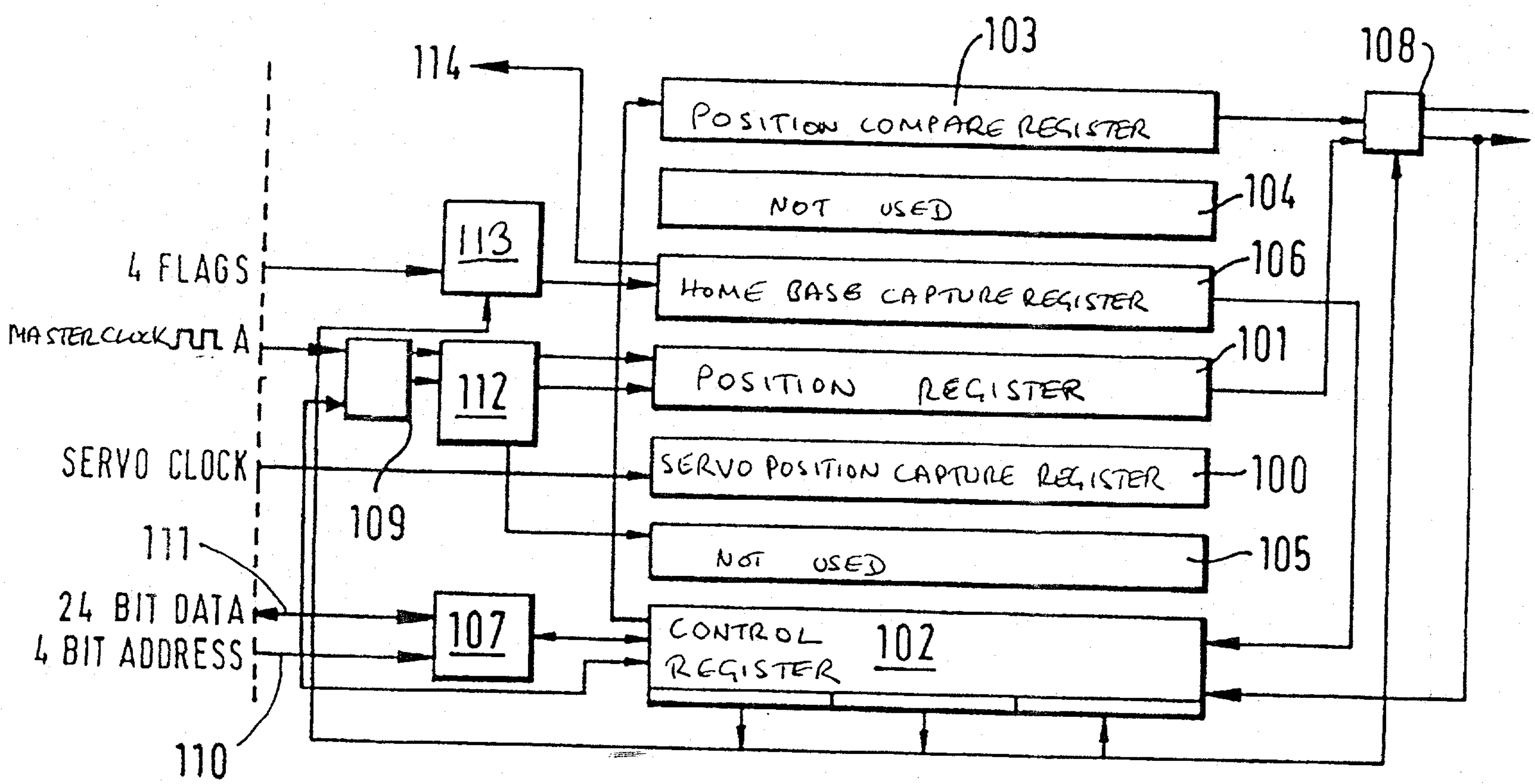
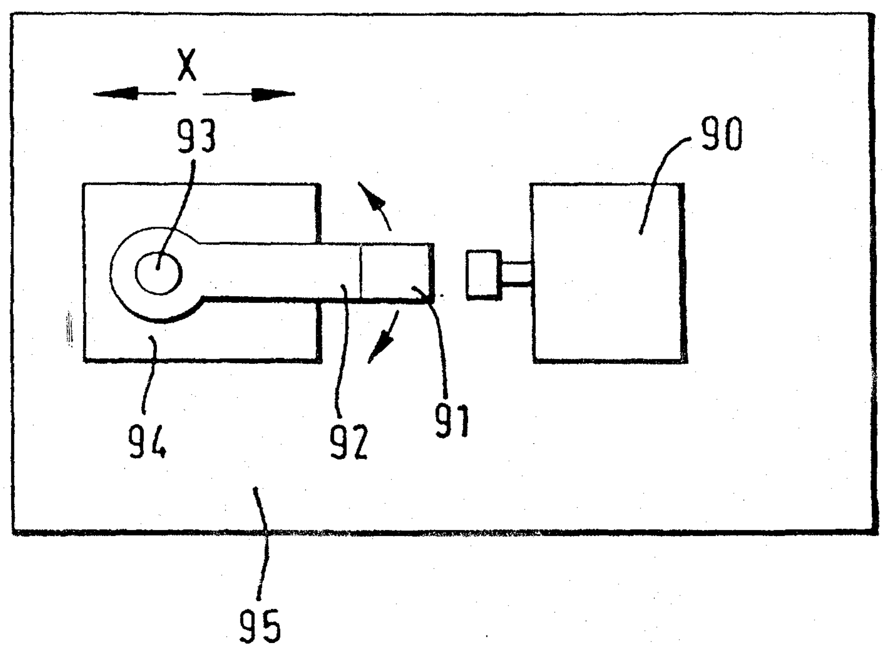

103
108
114
POSITION COMPARE REGISTER
NOT USED
104
4 FLAGS
113
HOME BASE CAPTURE REGISTER
106
MASTER CLOCK A
112
POSITION REGISTER
101
SERVO CLOCK
SERVO POSITION CAPTURE REGISTER
100
109
111
NOT USED
105
24 BIT DATA
4 BIT ADDRESS
107
CONTROL REGISTER
102
110

FIG. 11



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ELECTROMECHANICAL ACTUATOR

The present invention concerns a controllable actuator and also the machine tools which employ such an actuator.

There are several applications in which it is necessary to carry out very rapid and controllable movements. One example is the movement of cutting tools when used in machining non-axially symmetrical surfaces. Other examples concern moving reading heads to read magnetic or optical discs.

A concern of the present invention is to provide an actuator which can carry out rapid and accurate reciprocatory movements.

In accordance with a first aspect of the present invention there is provided an actuator comprising a pair of similar devices each responsive to electrical signals to generate reciprocatory displacements, and link means coupled to the devices to translate the respective displacements of the devices into a single set of reciprocatory displacements, the coupling between the link means and the devices being such that for each displacement generated by the link means the devices generate displacements in opposite directions.

As already mentioned, an important field of

application for such an actuator is found in the manufacture of contact lenses. It has been well-known for many years to manufacture contact lenses using diamond turning machines to generate rotationally symmetrical lenses. However, in many cases, for a contact lens to be appropriate it is necessary for the lens to be non-rotationally symmetrical. The demand for paraboloidal contact lenses which are necessary to counteract, for example, astigmatism has meant that the symmetrical turning process of the lens is combined with crimping so as to distort it along one of its axes. This procedure is both time-consuming and so inaccurate that it is difficult to predict the outcome.

It has for many years been appreciated that non-rotationally symmetrical surfaces can be generated using turning machines by additional movement of the cutting tool relative to the surface being turned along the axis of the spindle and in synchronism with the spindle rotation.

The theoretical requirements for the tool movement required to turn an off-axis paraboloid on axis are discussed in a paper by D.C. Thompson published in Volume 93 of the proceedings of the Society of Photo-Optical Instrumentation Engineers. A PhD thesis published in 1984 by Spivey Stevens Douglass of the University of Tennessee and entitled "A machining system

for turning non-asymmetric surfaces" describes a practical realisation of the theoretical paper given by D.C. Thompson. This paper describes an x-y lathe having what is now known as a fast-servo tool mounted on the x slide. Thus a fast-servo tool is a tool capable both of small controlled movement in synchronism with the rotation of the spindle of a lathe and of the normal movements imparted by the major components of the lathe.

Since the D.C. Thompson paper and the Spivey Stevens Douglass thesis, attempts have been made to provide a fast servo lathe capable of turning torroidal surfaces which can be used in the mass production of contact lenses. Before going on to discuss other problems which arise during the manufacture of contact lenses it will be appreciated that the production of paraboloidal mirrors is also commercially important and that the turning of such mirrors presents problems which are virtually identical to the turning of lenses. It will accordingly be appreciated that the present invention is applicable to the manufacture of all aspherical turned surfaces.

U.S. Patent Specification No. 4,680,998 discloses a lathe for use in the manufacture of contact lenses. The lathe is what is known as an Rho-θ lathe as distinct from an x-y lathe in that movement of the tool relative to the lens being turned has one major linear component

with the second major component of tool movement being arcuate. Both x-y and Rho-θ lathes have been used in turning operations long before the development of the fast tool servo. The movement of a tool in accordance with the x and y slides of an x-y lathe or the arcuate and linear movement of a Rho-θ lathe will hereinafter be referred to as macro-movements. In the generation of toric or rotationally non-symmetrical surfaces the cutting tool is given, as described in the D.C. Thompson paper for example, an additional micro-movement component which is synchronised with the rotation of lathe spindle.

One of the major problems which arises in the mass production of contact lenses is that in order to obtain satisfactory throughput the rate of rotation of the lathe spindle has to be high. In addition to the two conventional macro axes of the lathe it is necessary, as already described, to integrate two more axes of motion into the machine tool control system. The first of these is necessary to synchronise the micro-movement of the cutting tool with the rotation of the spindle. The second and more difficult motion to be controlled is the extent of the micro-linear movement of the fast tool servo in the spindle axis. Because of the rapid rotation of the lathe spindle it is accordingly necessary that any such micro-movements of the tool holder are extremely fast. Additionally, in order to generate a truly smooth lens surface it is necessary for such movements, and in

particular the extreme cutting position of the diamond tool, to be both extremely accurate and repeatable. If the micro movements of the fast tool servo can be controlled with sufficient accuracy then a major advantage arises in that the final product can be machined in a single turning operation and in some cases without the need for subsequent polishing.

In accordance with a second aspect of the present invention there is provided a lathe for machining non-axially symmetrical surfaces comprising means for moving a cutting tool holder relative to a workpiece mounted on the lathe spindle so that a rotationally symmetrical surface can be machined in the workpiece, fast tool servo means for imparting in synchronism with the rotation of the lathe spindle an additional movement to the cutting tool holder so that a non-rotationally symmetrical surface can be cut in a workpiece, wherein the means for moving the tool holder comprise a piezoelectric actuator.

In order that the present invention may be more readily understood an embodiment thereof will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic plan view of an x-y lathe;

Figure 2 is a side view of an actual lathe;

Figure 3 is a side section view through the fast servo tool of the lathe of Figure 2 taken in a vertical plane along the spindle axis of the lathe.

Figure 4 is a section view through line IV-IV of Figure 3;

Figures 5A and 5B are respectively side and front views of a damping arrangement used in the fast servo tool of Figures 3 and 4;

Figure 6 is a plan view of an embodiment of a multi-tool head;

Figure 7 is a block diagram of a control system used for the fast tool servo of Figures 3 and 4; and

Figure 8 is a block diagram showing the overall control circuitry used in the lathe of Figures 1 and 2;

Figure 9 is a block diagram of part of the circuit of Figure 8 in greater detail;

Figure 10 is a block diagram of a circuit forming part of Figure 9; and

Figure 11 is a diagrammatic plan view of a Rho-θ lathe.

Referring now to Figure 1 of the drawings this shows a lathe 1 which comprises a spindle 2 having a collet 3 on which can be mounted a lens blank. The spindle 2 is mounted on a linear slide 4 capable of controlled movement along the z axis. A diamond point cutting tool 5 is mounted on a fast tool servo 6 carried by a slide 7 controllably movable in the x direction which is orthogonal to the movement of the slide 4. Thus, the slides 4 and 7 provided normal, macro-movements of the tools of the kind which could be used to generate rotationally symmetrical surfaces whilst the fast tool servo 6 carries out the micro-movements necessary to create non-axially symmetrical or torroidal surfaces. A shaft encoder 8 generates signal synchronised with the rotation of the lathe spindle.

Figure 2 of the drawings is a side view showing the main components of an actual lathe constructed in accordance with an embodiment of the present invention. In this figure integers common with figure 1 have been given the same reference numerals. 20 is a video display unit used by the lathe operator to display input parameters etc together with a switch console 21 controlling off and on operation of the lathe. The main components of the lathe are conventional and as shown in

Figure 1 include the spindle 2 mounted on a Z-slide 4 so as to be movable in the z direction carrying a conventional collet on which a lens blank as a workpiece can be mounted. Opposed to the workpiece is the fast tool servo 6 which will be described in greater detail hereinafter. This fast tool servo includes a diamond cutting tool and is mounted on the x slide 7 of the lathe. As with the z slide the arrangement of the x slide is entirely conventional.

The movements of the main slides 4 and 7 of the lathe are achieved in an entirely conventional manner. Thus each slide is movable a nut mounted on a rotary screw which is driven by a DC motor. Mounted on the main body of the lathe closely adjacent to each slide is an 8 nanometre diffraction grating. Light shone onto this grating is reflected onto sensors on the slide which count interference fringes as the slide is moved relative to the grating. The resulting signal is used in a feedback control loop be to control the rotation of the associated DC motor. The arrangement of the screws, nuts, gratings and sensors is entirely conventional and does not form part of the present invention.

Referring now to Figure 3 of the accompanying drawings this shows the fast tool servo 6 in greater detail. In particular Figure 3 is a cross-section through the fast tool servo 6. Mounted within the fast

tool servo are a pair of piezoelectric stacks or actuators 31, each stack consisting of a plurality of piezoelectric elements. These actuator stacks act on a T-lever 32 having a cross-piece 33 and lever arms 34. The lower end of lever arms 34 of the T-lever are coupled by a stiff metallic flexure 35 to a tool beam 36 on which is mounted the diamond cutting tool. The tool beam 36 is capable of sliding movement in directions shown by the arrow A which are parallel to the Z axis of the Z slide 4 and to the rotational axis of the spindle 2. As can be seen from Figure 4, the T-beam has two dependent arms 34 and these arms carry vane dampers 49, the purpose of which will be described later.

The actuators 31 are mounted on a base plate 38 secured to the side walls 39 of the fast tool servo. The actuators 31 are held in tension between the crosspiece 33 and the base plate 38 in a manner which will be described hereinafter, the cross piece 33 being of composite construction. Thus the crosspiece 33 compresses a pair of parallel bars or blocks 40, 41. Sandwiched between the upper surfaces of the actuators 31 and the lower of the two blocks (41) are a pair of roller bars 42. Another roller bar 43 is sandwiched between the blocks 40, 41 and an adjustable bolt 44 is housed in a threaded hole on upper block 40. Lastly the crosspiece includes an arrangement 44 which also included a threaded bolt which holds in tension a metal flexure

45 secured to a cross pin 46. The roller bars are metallic rods of circular cross-section. The metal flexure 45 extends freely through the lower bar 43 and is held in the upper bar 33. Thus the actuators 31 are held compressed between the upper bar 33 acting via the bolt 44 and roller bar 41 onto the lower bar 33 and the base plate 38 by a resilient force exerted by the metal flexure 45. The movements of the lever arrows 34 are shown in Figure 3 by the arrows A.

The tension with which the actuators 31 are held between the cross piece 33 and the base plate 38 can be adjusted by using bolt 44. A block 47 is mounted on the side walls 39 of the fast tool servo and is connected to the lower block 40 by a flexure 48. The flexures 45 and 48 comprise sheet metal strips.

In the arrangement described alternate displacements of the actuators 31 are transmitted to the cross beam 41 and then to the arms 34 via the roller bars 42 which are located in shallow transverse grooves in the lower bar 41 and held by the tension of the flexure 45. The mechanical ratio by which the T-lever amplifies the displacements of the actuators is dependent on the spacing of the roller bars and the length of the arms 34 and in the present embodiment in approximately 10 or 11 to 1.

In operation of the fast tool servo the actuators 31 are alternately provided with a voltage in anti-phase and in the order of several hundred volts so that whilst one actuator is expanding the other is contracting. Each of the piezoelectric actuators contracts when positively energised and expands when negatively energised. The effect of this is that the T-lever 32 is rocked as described about a central axis defined by the flexure 45 so as to provide short, highly controlled linear movements of the tool beam 36 parallel to the Z axis of the lathe. The position of the tool beam 36, and thus of the cutting tool is measured by what is known as a Linear Voltage Differential Transformer (LVDT). The LVDT is shown at 50 in Figure 3 and comprises a central shaft which moves with the tool beam 36 relative to pick-up coils to provide an output signal corresponding to its displacement. This device 50 is entirely conventional.

Figure 5A shows a side view of one of the vane dampers 49. The vane dampers are made from 0.25 mm thick beryllium copper plates and are mounted in slots in respective damping blocks 49' secured to the base of the tool post by mounting bolts 38. A 10,000 centistoke damping fluid is also provided in the slots in the damping blocks and the result is that the vane dampers provide a moving damper which is extremely stiff in the axis of motion plus being compliant in the other axis. This compliance is provided by the freedom of the vanes

to bend and flex due to their 0.25 mm thickness. Furthermore the 0.25 mm thickness means that the vanes have minimum mass. This is another important requirement given the rapid accelerations and decelerations that the fast tool servo has to carry out. Preferably the damping fluid will be silicon based and the nominal gap between each face of a vane and its related opposite damping face would be 0.008 inches.

Referring now to Figure 6 of the accompanying drawings this shows a possible multi-tool arrangement in which the fast tool servo 6 is mounted on slide 4 in combination with four other standard tool holders. In this embodiment the diamond cutting tool of the fast tool servo is shown at 55, the conventional tool holders are shown at 52, 53, 54 and 55. Tool holder 52 is empty, tool holder 53 carries a power curve roughing tool 43A, tool holder 54 carries a base curve finish tool 44A and tool holder 55 carries a base curve roughing tool 45A. These additional tools can be used for machining non-toric surfaces and the arrangement shown in the figure means that a contact lens can be machined from a blank to its finished state without replacing tool heads. 56 is a conventional LVDT probe which can be used to measure the position of the lens blank.

The way in which the piezoelectric actuators are controlled in order to produce this reciprocatory

movement of the tool beam 36 will now be described with regard to Figure 7 of the accompanying drawings. It will be appreciated that the accuracy of movement of the tool beam 36 is of paramount importance. Another problem with providing this requisite accuracy is that the displacement of piezoelectric transducers is known to be non-linear with respect to applied voltage. However, the displacement is nearly linear with respect to charge across the piezoelectric element. Accordingly a voltage across a capacitor of known value placed in series with a piezoelectric transducer will indicate the charge across on the piezoelectric actuator and this charge signal can be used as a feedback signal to a control loop so that charge rather than voltage can be regulated. Thus by controlling charge on the piezoelectric actuator rather than voltage, the linearity of operation can be improved. This relationship between a linearity and charge is because piezoelectric actuators behave electrically like variable capacitors. In the present embodiment reference capacitors 60, 61 are placed in series with the pair of piezoelectric actuators 31. Thus any change in charge across a piezoelectric actuator will result in a corresponding change in charge across its associated reference capacitor. The capacitance of each piezoelectric actuator will change but since the capacitance of the associated reference capacitors remains constant, a voltage across each reference capacitor 60, 61 is proportional to charge across its

associated piezoelectric actuator. Thus the displacement of each piezoelectric actuator is nearly linear with the voltage across its reference capacitors. Accordingly in the present embodiment the voltage across the reference capacitors 60, 61 is used in a feedback loop to control the displacements of their associated piezoelectric actuators. It will be appreciated that if the capacity of the reference capacitor is large compared to the capacitance of its associated piezoelectric actuator, most of the voltage across the combination of piezoelectric actuator and capacitor is across the piezoelectric actuator. As each actuator is driven to hundreds of volts the presence of a large reference capacitor reduces the voltages for the feedback loop to normal signal levels of several volts.

As shown in Figure 7, the piezoelectric actuators are driven by associated high voltage amplifiers 62, 63. Depending on the type of high voltage amplifier used to drive the actuator/reference pair each reference capacitor may operate at several hundred volts relative to ground. Any connection to the reference capacitor to sense the voltage must be of high impedance to avoid loading the high voltage circuit. It is possible to measure the reference capacitor voltage with a pair of voltage dividers to reduce the common mode voltage leading to the associated amplifier. However it is difficult to match the resistors in the divider network

for good common mode rejection and the resulting signal-to-noise ratio may cause problems. The present embodiment employs a pair of isolation amplifiers 64, 65 mounted across the reference capacitors 60, 61. This provides both high impedance and good common mode rejection. The outputs of the isolation amplifiers 64, 65 are taken to respective summing circuits 66, 67 where they are combined with an error signal derived both from the main control system for the lathe as a whole and with a position signal generated by the position sensor 50. As the actuators 31 operate in anti-phase the control circuit of one actuator incorporates an inverter 68.

It will be appreciated that whilst the charge loop measurement can be used to linearise piezoelectric actuators normally used in open loop situations, it has great benefits when combined with position loop control.

It will also be appreciated that the piezoelectric actuators and their reference capacitors will have some leakage. This leakage works as a resistor in parallel with the capacitor which tends to discharge the capacitor. The leakage for piezoelectrics is quite low and reference capacitors are available with low leakage as well. However if the reference capacitor discharges to zero the position loop will still be able to maintain position because the high voltage amplifier will be able to supply full voltage to the piezoelectric. In fact if

the feedback voltage from the reference capacitor is zero the charge loop merely acts as an additional gain in series with the position loop gain. If the actuator discharges faster than the reference capacitor eventually all the voltage available from the high voltage amplifier will be across the reference capacitor and the actuator will not move. In order to combat this the present embodiment provides an intentionally added leakage resistance to each reference capacitor so as to ensure that the reference capacitors discharge faster than their associated actuators. These leakage or shunt resistors are shown in Figure 7 at 69.

The addition of the shunt resistors 69 to the reference capacitors also solves the problem of initial conditions at start-up. Before the circuit is switched on there may be a mismatch between the charge on the piezoelectric actuator and its associated reference capacitor. If the difference is large enough there will be a large error signal in the charge loop and the charge loop will go into saturation at start-up. The actuator will go to one extreme or the other despite the position loop attempting to drive the actuator to the correct position. The shunt resistor will eventually reduce the feedback signal from the reference capacitor to zero allowing the position loop to drive the actuator to the correct position.

When the fast tool servo is in operation the position signal from the position sensor 50 can be demodulated using peak sampling techniques to ensure that bandwidth is not limited by carrier frequency and introduce negligible phase shifts in the feed back loop. In the present embodiment simple demodulation is carried out in circuit 70. This position output is supplied to a summing junction 71 and is compared in this summing junction with an analogue position demand signal supplied at input 72 of the summing junction from the main control circuitry of the lathe. The resulting error signal on line 73 drives the amplifiers 62, 63 via circuit 74. This circuit is what is known as a forward loop controller and is matched for the characteristics of the subsequent drive circuitry of the actuator and the physical constraints of the fast tool servo. It includes a phase advance circuit, low frequency filters, and a notch filter tuned to the natural frequency of the fast tool servo.

From the foregoing it will be appreciated that it is important that the fast tool servo be carefully synchronised with the x and y slide motions of the main lathe to maintain accuracy. As already described, the fast tool servo feedback control loop is independent of the x and z slide control. However it will also be appreciated that it is essential that the linear movements of the diamond cutting tool are synchronised

with the rotation of the main lathe spindle in order to enable toric surfaces to be machined. This is achieved by the shaft encoder 8 which is an incremental encoder and is mounted on the end of spindle 2, and by the overall control circuitry of the lathe.

This overall circuitry will now be described in greater detail with regard to Figure 8 of the accompanying drawings.

This control system comprises what is known as a PMAC (TM) controller 80. PMAC stands for "Programmable Multi Axis Controller" and the controller 80 is manufactured by the Delta Tau Corporation of the United States of America. The controller 80 receives an input from the shaft encoder 8 which provides a time based master for the entire controller. Thus when the PMAC carries out a motion programme controlling the operation of both the lathe in the x and z axes and the linear motion of the fast tool servo its speed of execution is directly proportional to the frequency of the master encoder. Thus in execution the PMAC controller 80 automatically handles any deviation from the time base master and scales the speed of execution in direct proportion. This technique allows the entire trajectory of the cutting tool relative to the blank to be calculated off-line. Thus in the embodiment being described the procedure for generating a toric shape is

as follows. All the trajectory information required to control the fast tool servo and the main X and Z slides is generated prior to the machining operation and stored in a job file indicated at 81. This job file is generated by a general purpose computer 86. The contents of this job file are streamed into the PMAC controller 80 via a dual port RAM 81 and into a rotary buffer 83. Essentially this buffer 83 stores the required coordinates and reads these coordinates out in synchronism with the time base clock generated by the clock circuit 84 from the output of the shaft encoder 8. The PMAC 80 includes a control processor 85 which not only computes the control signals for the macro movements of the z axis and x axis of the lathe and the micro movements of the fast tool servo but also includes a spline interpolation mode so that every point in the trajectory of the cutting tool does not have to be programmed. In the present embodiment the spline interpolation mode computes nine intermediate points per programme point. Accordingly by using 24 programme points per revolution, that is a point every 15 degrees, the worst interpolation errors are negligible.

The embodiment described also has the ability to control the orientation of the meridian of the lens workpiece to better than ±1 degree. This is achieved in the control system by freezing and arming the time base so as to capture the spindle position and then comparing

the captured spindle position with the programmed meridian orientation stored in the job file. This comparison is carried out in a compare register in the controller. Once the spindle position has been established with respect to the required orientation the time base is triggered by the output of the compare register and this ensures synchronisation with the workpiece spindle.

The controller 80 is shown in greater detail in Figure 9 of the drawings. The basic PMAC controller is capable of controlling 8 axes. In the present embodiment control of only 3 axes is required, namely the X and Z axes of the lathe and the W axis which represents the movement of the fast tool servo.

In Figure 9 the input from the dual port RAM 81′ is shown at 87. The input from the host computer 86 is supplied to the controller 80 via the conventional buses generally indicated at 88. The output of the controller 80, indicated in Figure 8 as the trajectory control circuit 85, is also shown as 85 in Figure 9.

In the standard PMAC controller there are four similar gate circuits of the type DSP-Gate. In the present embodiment three of these gate circuits are used, one for each of the three axes X, Z and W. Only one DSP-Gate circuit, shown in Figure 9 at 89, will be described

in greater detail as the functions of the other two gate circuits for controlling the X and Z axes of the lathe are well known and entirely conventional.

Referring now to Figure 10 of the drawings, this shows the DSP-gate 89 which is used to control the meridian orientation in the manner already described in the specification. It will be seen that this gate has seven main registers 100-106. In the present embodiment the registers 104 and 105 are not used. Of the registers used, register 102 is a control register which has access to all the other registers and which communicates with the control circuit 80 via a bus and data control circuit 107 which is connected to a 24 bit data bus 110 and a four-bit address line 111 by means of which data on line 110 can be written into and read out of control register 102.

Register 101 is a 24-bit up/down position register and the master clock derived from shaft encoder 8 is supplied to register 101 via a digital filter 109 and a decode circuit 112. The register 101 is thus a continuous indication of the spindle position.

Register 100 is referred to as a servo position capture register and is supplied on line 113 with an index signal derived from the shaft encoder which indicates the starting point of a spindle revolution.

The servo position capture register 100 when clocked by the index signal acts to capture the value in register 101.

Register 103 is referred to as a position compare register and acts to compare a value loaded into it from the control register 102 with the value of the position register 101. The value loaded by the control register is the value as captured in the servo position capture register. The outputs of position compare register 103 and of position register 101 are taken to a gate 108 and on parity between the contents of the two registers a signal is sent from gate 108 both to the control register 102 and as a flag to a position capture trigger control circuit 113. The output of circuit 113 triggers a home capture register 106 the output 114 of which provides an external time base trigger to circuit 80.

Figure 11 of the accompanying drawings shows a fast tool servo of the kind described mounted on a Rho/θ lathe. The lathe comprises a spindle 90 for carrying a workpiece such as a lens blank. The fast tool servo is shown at 91 and is mounted on an arm 92 pivotally mounted at 93 or a slide 94 movable as shown by the arrows X over the base 95 of the lathe in the direction of the spindle axis. As in the embodiment already described the operation of the fast tool servo is synchronised with the spindle revolution so as to be capable of cutting axially non-symmetrical shapes.

CLAIMS

1. An actuator comprising a pair of similar devices each responsive to electrical signals to generate reciprocatory displacements, and link means coupled to the devices to translate the respective displacements of the devices into a single set of reciprocatory displacements, the coupling between the link means and the devices being such that for each displacement generated by the link means the devices generate displacements in opposite directions.

2. An actuator according to claim 1, including a position sensor for detecting displacements generated by the link means, and means responsive to the position sensor to provide closed loop control of the actuator.

3. An actuator according to claim 2, wherein the link means comprise a pivoted lever, and the devices are coupled to opposite sides of the pivot axis of the lever.

4. An actuator according to claim 3, wherein the lever has an arm extending from the pivot point, the arm being adapted to reciprocate a mounting for a cutting tool.

5. An actuator according to claim 4, wherein the lever arm carries at least one damping vane movable within a

slot to provide damping in the plane of pivotal movement of the lever.

6. An actuator according to claim 5, wherein the or each slot contains a damping fluid.

7. An actuator according to any preceding claim, wherein the devices are piezoelectric stacks.

8. An actuator according to claim 7, wherein each piezoelectric stack has a reference capacitor in series therewith so that the charge across the capacitor represents the displacement of the stack.

9. An actuator according to claim 8, wherein each reference capacitor has an associated isolation amplifier for measuring the charge thereacross.

10. An actuator according to claim 8 or claim 9, wherein each reference capacitor has an associated leakage resistor.

11. A lathe for machining non-axially symmetrical surfaces comprising means for moving a cutting tool holder relative to a workpiece mounted on the lathe spindle so that a rotationally symmetrical surface can be machined in the workpiece, fast tool servo means for

imparting in synchronism with the rotation of the lathe spindle an additional movement to the cutting tool holder so that a non-rotationally symmetrical surface can be cut in a workpiece, wherein the means for moving the tool holder comprise a piezoelectric actuator.

12. A lathe according to claim 11 and including a position sensor for sensing the location of the tool holder so as to provide a closed feedback loop for controlling the fast tool servo means.

13. A lathe according to claim 11 or claim 12, wherein the means for moving the tool holder comprise a pair of piezoelectric actuators which act in antiphase to move the tool holder.

14. A lathe according to any one of claims 11 to 13 and including a control circuit for providing a demand signal to drive the or each piezoelectric actuator, and a shaft encoder coupled to the lathe spindle for providing a time base for the control circuit.

15. A lathe according to claim 14, wherein the control circuit includes a system time base, and means for synchronising the system time base with the spindle position.

16. A lathe according to claim 15, wherein the synchronising means comprise a compare means for comparing the spindle position as indexed by the shaft encoder with a spindle position derived from a control register to generate a time base trigger for the control circuit.

17. A lathe according to any one of claims 11 to 16, wherein the or each piezoelectric actuator is associated with a reference capacitor in series with the actuator, and further including control means response to the change across the or each reference capacitor to provide a substantially linear feedback loop for controlling the operation of the or each piezoelectric actuator.

18. A lathe according to claim 17, and including a position sensor responsive to the position of the tool holder to provide a position signal, means for combining the position signal as measured by the position sensor with a demand signal indicative of the desired position of the sensor and means for driving the or each piezoelectric election actuator in accordance with the output of said means for combining.

19. A lathe according to any one of claims 11 to 18, and including means for storing a plurality of values representative of the desired positions of the tool head

required to generate a desired non-rotationally symmetrical surface, means for computing the requisite movements to be imparted to the main lathe axes and to the tool holder of the fast tool servo so as to generate control signals for controlling movement of the main lathe axes and the movements of the fast tool servo, and a shaft encoder coupled to the lathe spindle to provide a master time base for the control means.

20. A lathe according to claim 19, wherein the control means include means for receiving a job file generated externally of the lathe, the control means processing the job file to generate the control signals.

21. A lathe according to claim 20, wherein the job file contains a plurality of points expressing desired location of the cutting tool holder, and the control means extrapolates between the points to generate intermediate points.

22. A lathe according to any one of claims 11 to 21, wherein the lathe is an x-z lathe and the spindle is mounted on the x-slide and the fast tool servo is mounted on the z-slide.

23. A lathe according to any one of claims 11 to 21, wherein the lathe is an Rho-θ lathe.

24. A process of manufacturing a workpiece comprising mounting the workpiece on the spindle of a lathe, rotating the spindle and moving a cutting tool in synchronism with the rotation of the spindle so as to machine a non-axially symmetrical surface in the workpiece, the cutting tool being driven by a piezoelectric actuator.

25. A process according to claim 24 or claim 25, wherein the lathe is as claimed in any one of claims 11 to 23.

26. A process according to claim 25, wherein the workpiece is a lens blank for a contact lens.

27. A process according to claim 26, wherein the final lens does not require a polishing operation before use.

28. An actuator substantially as hereinbefore described with reference to Figures 3, 4 or 5.

29. A lathe substantially as hereinbefore described with reference to any one of the Figures of the accompanying drawings.

The Patent Office

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Claims searched: 1-10

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Date of search: 10 October 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1E-EA,EAGF,EAGG,EB,EX ; H2A-AKS8

Int Cl (Ed.6): H02N-2/02,2/04 ; H01L-41/09

Other: Online WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	US 4825894 ((MOOG) e.g. Fig.1	1

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